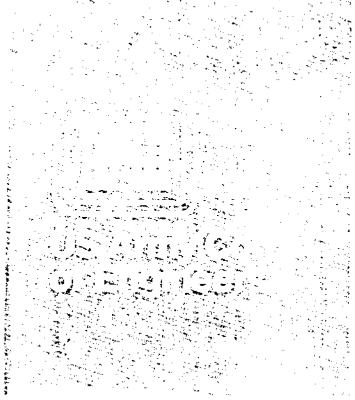

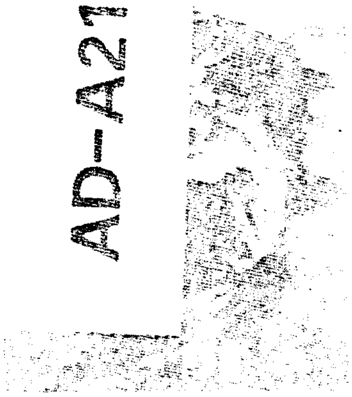

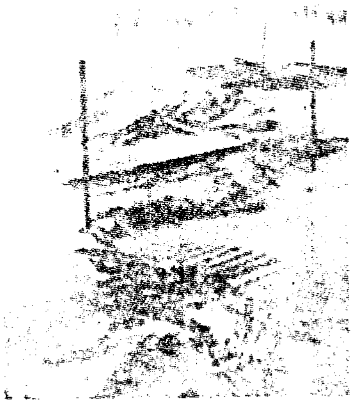

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ARCHEOLOGICAL INUNDATION STUDIES: MANUAL FOR RESERVOIR MANAGERS

by

John A. Ware

Museum of New Mexico
Santa Fe, New Mexico 87504-2087

September 1989

Final Report

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Development and operation of freshwater reservoirs create a variety of potential impacts on archeological resources. These impacts accrue from several sources, including mechanical, biochemical, and human and other processes associated with the reservoir environment. This report summarizes the findings of the National Reservoir Inundation Study, a multi-agency project designed to assess the range of effects of inundation on archeological resources. Potential effects are discussed within three discrete zones of differential impact: (a) the conservation pool, (b) the fluctuation zone, and (c) the backshore zone.

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PREFACE

In 1981, the National Park Service published a two-volume report on a 5-year, multidisciplinary study designed to investigate and evaluate the impacts of freshwater inundation on archeological and other cultural resources. The purpose of the present study is to summarize and condense the results of the National Reservoir Inundation Study, to present a model for effective management of cultural resources in a reservoir environment, and to suggest directions for future research.

This study was sponsored by Headquarters, US Army Corps of Engineers (HQUSACE), as part of the Environmental Impact Research Program (EIRP), under Work Unit 32357. Dr. John B. Bushman, Mr. David P. Barlow, and Mr. Dave Mathis, HQUSACE, are the EIRP Technical Monitors.

This report was prepared by Dr. John A. Ware, Director of the Laboratory of Anthropology, Museum of New Mexico, Santa Fe, NM, under Contract No. DACW3987P1062 with the US Army Engineer Waterways Experiment Station (WES). Study Manager for the project was Dr. James J. Hester, formerly of WES. This study was conducted under the general supervision of Dr. John J. Ingram, Chief, Water Resources Engineering Group, Environmental Laboratory (EL), WES; Dr. Raymond L. Montgomery, Chief, Environmental Engineering Division, EL; and Dr. John Harrison, Chief, EL. Dr. Roger T. Saucier is the EIRP Manager. Appreciation is extended to Dr. John C. Belshe of HQUSACE for originating the idea to produce this report and to Mr. Daniel J. Lenihan, Chief of the National Park Service Submerged Cultural Resources, for assistance with the current project. Editor of this report was Ms. Lee T. Byrne of the Information Technology Laboratory, WES.

Commander and Director of WES during publication of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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CONTENTS

ARCHEOLOGICAL INUNDATION STUDIES: MANUAL FOR RESERVOIR MANAGERS

PART I: INTRODUCTION

1. Twentieth century demands for water, electricity, and flood control in the United States have resulted in the damming and impoundment of most of America's large rivers and streams. The impact of such activities on North American archeological and historical resources is difficult to measure. Concern for mitigating the impact of dam construction and reservoir impoundment resulted in the Reservoir Salvage Act of 1960, as amended in 1974, which requires that any US agency undertaking dam construction must provide written notice to the Secretary of the Interior, who shall then cause a survey to be conducted for archeological sites, either by the Department of the Interior or by the Federal agency undertaking the construction project.

2. An underlying premise of the Reservoir Salvage Act is that freshwater inundation of archeological resources is fundamentally destructive and that the only way to effectively mitigate adverse impacts is through a program of intensive survey and salvage excavation of endangered resources. These assumptions came under increasing scrutiny in the 1960s as more and more Federal dollars were being expended on archeological salvage in reservoirs and waterways. Although most archeologists argued strenously for a continuation of salvage efforts, a growing opinion shared by some archeologists, reservoir managers, and managing agencies was that inundation represents the ultimate form of archeological preservation (Jewell 1961). According to this view, the silt and water column of a freshwater reservoir create an ideal long-term preservation environment for fragile archeological and historic cultural resources.

3. In 1975, four Federal agencies, the National Park Service, the Bureau of Reclamation, the US Army Corps of Engineers, and the Soil Conservation Service, determined to resolve the debate through intensive research. The result was the National Reservoir Inundation Study (NRIS), a 5-year program designed to conduct basic research on the effects of freshwater inundation on cultural resources. After 5 years of field and laboratory research on inundation processes and cultural impacts, the NRIS concluded: (a) the effects of freshwater inundation on archeological resources are overwhelmingly

detrimental, (b) some archeological values are more susceptible to adverse impacts than others, (c) in situ site protection is a viable mitigation alternative to excavation only in limited circumstances, and (d) archeological mitigation plans should be incorporated into the reservoir construction planning process as early as possible in order to effectively address the entire range of adverse effects (Lenihan et al. 1981).

4. The purpose of this report is to summarize and condense some of the more important results of the NRIS for reservoir managers who must make informed decisions about the long-term preservation and management of cultural resources.

PART II: CULTURAL RESOURCES: A HIERARCHY OF VALUES

5. An understanding of freshwater inundation impacts requires the identification of potentially destructive reservoir processes and a determination of the effects of those processes on a wide range of cultural resources. According to Scovill, Gordon, and Anderson (1972), a cultural resources:

> includes any source of information about the lives of past peoples including, but not limited to, artifacts, architecture, plant and animal remains, local geology, soil composition, topography, and the modern environment. . . . Analysis and interpretation of the data contained in archaeological resources requires examination of their total physical and ecological context.

6. Because of the magnitude and scale of inundation effects, such a general, all-inclusive definition of cultural resources is appropriate when assessing the destructive potential of freshwater inundation. Reservoir construction and freshwater inundation affect not only cultural sites and their contents, but entire cultural and environmental systems. If one is to anticipate and mitigate the entire range of adverse effects, one must identify the entire range of threatened values. The NRIS approached the problem of cultural resource definition using a hierarchical array of cultural values that encompassed everything from the regional ecosystem down to the individual artifact attribute (Table 1).

Large-Scale Values

7. Even before the pioneering settlement pattern studies of Gordon Willey in the Viru Valley of Peru (Willey 1953), archeologists have known that important cultural information exists beyond the boundaries of archeological sites and activity loci. As defined by the NRIS, "large-scale values" include regional ecological patterns (e.g. floral and faunal distributions and communities); regional geomorphological data; large-scale cultural features such as roads, agricultural fields, waterworks, etc.; and regional scale cultural relationships such as settlement patterns, resource exploitation zones, etc. To the extent that inundation adversely affects the ability to collect information on the regional environment, resources contained in that environment, regional data needed to reconstruct elements of the past environment, and large-scale cultural features and cultural relationships, significant

Table 1

Two-Dimensional Matrix Indicating Prediction of Freshwater Inundation Effects on Cultural Values

Impact Categories	Large-Scale Data	Medium-Scale Data	Small-Scale Data
		Archeological Resources	
	Regional ecological considerations such as geomorphology, settlement patterns, faunal and floral distributions.	Site contextual data, stratigraphic and spatial relationships within a site.	Differential impacts on common cultural materials including artifacts, features, analytical properties, etc.
		Impact Categories	
Mechanical impacts	Mechanical (siltation and erosion) and biogeochemical impacts to the reservoir drainage basin, including gross geomorphological changes;	Nearshore wave action erosion and siltation of sites and site deposits.	Mechanical abrasion, freeze-thaw, and wet/dry impacts to artifacts and other cultural materials.
Biochemical impacts	impacts to preinundation floral and faunal communities, etc.	Biochemical alteration of site soil and contextual relationships.	Differential biochemical deterioration of archeological material categories.
Human and other impacts	Dam and borrow pit construction, roads, clear-cutting, etc.	Vandalism, recreational use. Impacts to shoreline by grazing animals; impacts by invader plant species, etc.	Removal of selected artifacts by collectors, etc.

Source: Lenihan et al. 1981.

"cultural" information may be lost. The impact of freshwater inundation on the environmental context of a cultural resource data base is one of the most important large-scale effects of reservoir construction.

8. When a freshwater lentic ecosystem is superimposed on a terrestrial and riverine ecosystem, the result is a mass mortality or migration of terrestrial plants and animals and the destruction of important environmental data from an entire catchment basin. Significantly, these changes are not necessarily limited to the permanent pool zone of the reservoir, but may extend to the backshore and downstream zones as well (Lenihan et al. 1981). Destruction of an ecosystem has far-reaching implications for the interpretation of cultural resources. Accurate paleoenvironmental reconstruction in archeology relies on the ability to reconstruct contemporary environmental patterns (Butzer 1971). Since the present is so often the key to the past in paleoenvironmental studies, the destruction of modern environments and landscapes may make it impossible to understand past culture-environmental relationships. The NRIS stated it succinctly in the following:

> In addition to the cultural features and patterns that are superimposed on the modern landscape, significant "cultural" information resides in the landscape itself, especially in the distribution of plants, animals, soils, geomorphologic features, and other data that provide a window on modern environmental conditions or a record of past environmental change (Lenihan et al. 1981).

9. In addition to regional environmental data, a reservoir impact zone may also contain large-scale cultural features such as roads, trails, fences, boundary markers, field borders, walls, waterworks, fortifications, etc. Along with large-scale features are large-scale patterns and spatial relationships that may provide important clues about the economic and social dimensions of life in the past. For example, archeological sites are often component parts of larger settlement systems, and individual sites may be clustered in relation to important environmental, resource, and landscape variables (i.e., water, plant and animal resources, soils, etc.). Freshwater inundation typically alters or destroys these patterns of intersite and site-environment relationships.

Medium-Scale Values

10. Medium-scale cultural values consist of archeological sites and historic structures, their internal integrity, and the stratigraphic and spatial relationships that make sites observable and definable features.

11. Sites can be defined as ". . . any place, large or small, where there are traces of human occupation or activity" (Hole and Heizer 1973). Sites consist of things, including portable objects (called artifacts) and nonportable facilities (such as architecture), but sites are more than random collections of artifacts and architectural remains. A site is a three-dimensional (3-D) matrix of objects and facilities in which the stratigraphic and spatial relationships among the materials are often as important as the materials themselves (Figure 1). The relationships among the various artifacts and facilities comprising a site are known collectively as the archeological context, defined as "the environment within which things . . . are found or within which they operate" (Hole and Heizer 1973).

12. A site, then, is an assemblage of cultural objects and their relationships with other objects. The set of ordered relationships that comprise

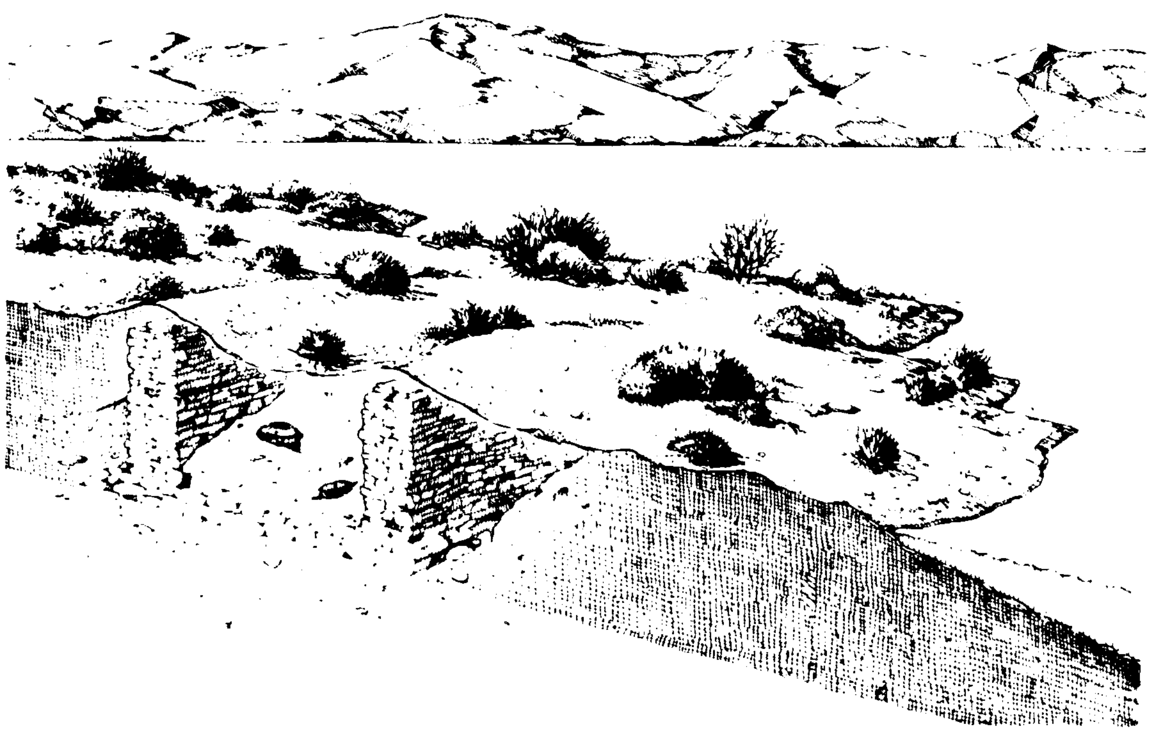

Figure 1. Schematic representative of the 3-D configuration of archeological site

the archeological context of a site is the result of the nonrandom output of human activities that are ordered in time and space. If inundation alters these relationships or if erosion compresses stratigraphy or redistributes objects in space, important cultural information is lost:

> Artifacts can be perfectly preserved, but if their spatial and stratigraphic relationships are altered or destroyed, much of their scientific value is irretrievably lost (Lenihan et al. 1981).

Small-Scale Values

13. Archeological information consists of objects and their relationships. At the medium scale of cultural values, the archeologist is concerned primarily with relationships among objects and the preservation of cultural context. At the smallest scale of the values hierarchy, the concern shifts to the objects themselves. If artifacts are not preserved, there is little hope of discerning relationships among artifacts. Clearly, differential destruction and preservation of cultural objects affect cultural values at every level of the cultural resource hierarchy.

14. At the smallest scale of cultural values, the concern is for impacts to artifacts, artifact assemblages, and artifact attributes (i.e., differential preservation of entire material classes, loss of artifact attribute information, and inundation effects on analytical techniques that are applied at the artifact or attribute level). Every artifact and facility has a set of measurable characteristics and attributes, and each attribute informs about some aspect of human behavior. The paint on a potsherd, the wear pattern on a stone flake, the materials used in the construction of a house, all of these bits of information are important links in the chain of inference about past human behavior. To the extent that inundation alters or destroys the attributes of artifacts and facilities, important behavioral information is lost.

15. To briefly summarize, cultural resources consist of material remains and the patterned relationships among material remains at a variety of levels. Responsible cultural resource management acknowledges the complexity and hierarchical organization of cultural information and develops strategies that preserve information at all relevant levels. One of the keys to developing effective strategies is to anticipate adverse impacts before they occur. In a freshwater reservoir, adverse impacts come in a variety of forms.

PART III: RESERVOIR PROCESSES

16. Several inundation-related processes affect the preservation of cultural resources in reservoirs and waterways. The NRIS identified three broad categories of impact: (a) mechanical, (b) biochemical, and (c) human and other processes. Figure 2 shows the interplay between these impact categories and cultural resources.

Mechanical Processes

17. Mechanical processes include the physical erosion and deposition processes associated with any large body of water. Included in this general category are wave and water motion, reservoir siltation from backshore runoff and stream inflow, and saturation and slumping of shoreline and submerged geological strata.

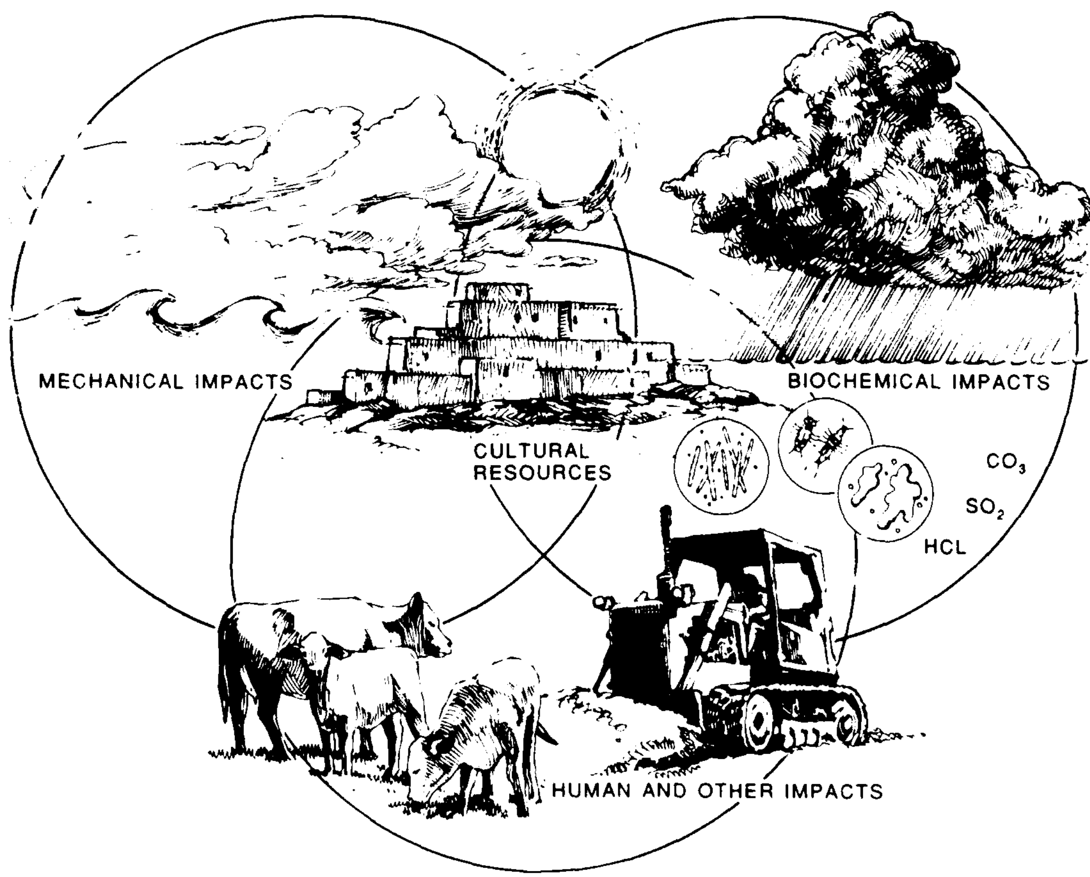

Figure 2. Inundation-related impact processes which affect the preservation of cultural resources in reservoirs and waterways

18. Wave action is the most important mechanical impact to cultural resources in reservoirs. Fluid motion in the form of water waves is most often generated by wind blowing over water, but destructive waves can also be caused by power boat wakes and tectonic disturbances (Duane et al. 1975). Because of their elliptical orbit, water waves move very little solid material in deep water, but shoaling waves may release a great deal of energy in the shallow water of the reservoir nearshore.

19. Wind-generated wave and erosion potentials can be predicted with some degree of certainty. Wave height and period are primarily a function of wind velocity, duration, and size of reservoir fetch (Komar 1976). The width of the high-energy beach zone is, in turn, primarily a function of wave height. At a depth of one-quarter the average wave height, water motion is only 21 percent of surface motion; at a depth of one-half wave height in the beach zone, motion is only 4 percent of surface water motion. The erosive potential of shoaling waves is also conditioned by such variables as shoreline slope, the stability of shoreline sediments, and the presence or absence of vegetation buffers.

20. The average reservoir shoreline will achieve an equilibrium profile if the reservoir water level remains relatively stable. The mechanical process begins as waves attack the newly formed shoreline, removing fine silty materials to deep water and depositing heavier fractions in an offshore shoal. As the shoal gets larger, nearshore wave energy decreases and erosion rates are reduced.

> As the size of the offshore shoal increases, wave energy reaching the shore decreases, until a certain limiting form is achieved in which most of the wave energy capable of eroding the shore is dissipated in the offshore shoal (Kondrat'yev and Grigor'yeva 1974).

21. Unfortunately, the self-limiting process of nearshore shoal formation is affected by pool level fluctuations. As reservoir pool levels draw down, offshore shoals are eroded, and wave action in the nearshore begins anew. Consequently, reservoirs subjected to large annual pool-level fluctuations may never achieve stable shoreline profiles.

22. In addition to direct wave assault, nearshore currents have the potential for altering the littoral topography of a reservoir. The strength and entrainment capacity of nearshore currents are primarily a function of wave height, which varies with fetch size and local meterological variables.

The impact potential of nearshore currents in small reservoirs is negligible, but in large reservoirs it can be significant.

23. Whereas erosion is the dominant mechanical force in the reservoir nearshore, in the deepwater zones of a reservoir, deposition processes predominate. Reservoir sedimentation rates vary depending on the geology and climate of the reservoir watershed. On the silt-laden streams of arid regions, reservoir sedimentation can be extremely rapid, whereas in more temperate regions, stream and backshore erosion rates are reduced by vegetation stabilization of topsoils. Nevertheless, in all reservoirs, sedimentation is an inexorable process that ultimately limits the effective use-life of the impoundment.

24. In general, sedimentation tends to enhance cultural resource preservation by providing a sediment buffer against mechanical and other forms of destructive reservoir processes. However, cultural resources buried under a deep silt and water column are no longer accessible for research, and little is known about the long-term impacts of deep sediment burial on fragile cultural deposits. In addition to loss of access to the cultural resource data base, two processes in the reservoir offshore may be of concern to cultural resource managers: (a) reservoir siltation impacts to deeply buried cultural sites and (b) changes in basin morphology resulting from sediment saturation, slumping, and creep.

25. There have been no definitive studies of the impacts of heavy siltation on cultural sediments; the effects, for example, of weight load, soil liquefaction, etc., are not known at this time. However, it is only prudent to assume that these processes may result in some adverse impacts to fragile cultural remains. Subaqueous landslides and sediment shifts are known to occur in the deepwater zones of reservoirs. According to Sherman (1968), subaqueous slope failures are especially common on initial submergence, especially in unconsolidated talus slopes.

26. Although erosion is usually negligible in the deepwater zones of reservoirs, mechanical impacts can and do occur in deep water as a result of: (a) initial dam construction, including activities such as borrow pit construction, rock blasting, vegetation clear cutting, road building, etc.; (b) wave action during the initial reservoir filling episode; and (c) subaqueous landslides and sediment shifts.

Biochemical Processes

27. The chemical and biological environment of a freshwater reservoir is of primary concern in the differential preservation and destruction of inundated cultural materials. The chemical composition of a freshwater reservoir is primarily a function of climate, geology, biota, human activity, and time (Lenihan et al. 1981). Water quality studies suggest that the ionic concentrations of most freshwater reservoirs consist primarily of four cations and three anions, the dominant cations being calcium, sodium, magnesium, and potassium, and primary anions consisting of bicarbonate, sulphate, and chloride (Livingston 1963).

28. The two most important variables influencing ionic concentrations in reservoirs are (a) climate, primarily evaporation and precipitation rates, and (b) soil chemistry (Lenihan et al. 1981). When evaporation rates are high, dissolved solid concentrations tend also to be high; when precipitation exceeds evaporation, dissolved solids will be more dilute. Other factors affecting water chemistry in reservoirs include the organic content of the soil, the amount of organic material that is inundated in the reservoir, circulation and water exchange rates within the reservoir, water depth and thermal stratification, water temperature, and ionic concentrations of inflowing streams and surface runoff (Sylvester and Seabloom 1964).

29. Whereas climatic effects on water chemistry are fairly stable through time (assuming a stable climatic regime), soil contributions change as chemicals are leached from inundated soils and as inundated soils are covered with a sediment blanket. Although there are few studies of reservoir aging effects on water chemistry values, it is perhaps safe to assume that as a reservoir ages and as sediments accumulate, the effects of soil chemistry on water chemistry decline. Consequently, the older the reservoir, the more its water chemistry is determined by stream inflow and precipitation/evaporation rates in the drainage basin.

30. Water chemistry concentrations are also affected by water depth, location relative to closure and stream inflow, and seasonal variability. In general, increased water depths are associated with greater concentrations of sulphate, iron, sodium, magnesium, zinc, hardness, and conductivity (Herrmann and Mahan 1977). In thermally stratified reservoirs, there may be significant differences in water chemistry among the various temperature zones.

31. With respect to spatial variability, the highest ionic concentrations are found in deep waters near the dam, with the lowest concentrations near the point of stream inflow. Studies by Ward and Karaki (1971) suggest that there may be a 10- to 30-percent difference in water chemistry values between dams and inlets on many reservoirs. Seasonal variability may also be significant. In general, inflow of water in late spring and summer is less concentrated than runoff in winter and early spring (Herrmann and Mahan 1977).

32. Once the water chemistry of a reservoir is established, there is a question about its overall significance in cultural resource management. Cultural resources are not simply suspended in the water column, but are part of a soil matrix with its own chemical characteristics. Depth within the submerged soil column will largely determine oxygen-reduction (redox) potentials, which in turn will influence the chemistry of the water and the types and varieties of organisms present. Below the highly oxygenated mud-water interface, redox potential decreases with depth (Mortimer 1941, 1942). In deeply buried anaerobic sediments, preservation conditions should be ideal, but the long-term effects of anaerobic burial on common cultural materials are still poorly understood.

33. The biological community of a reservoir is influenced by both water chemical and physical parameters, such as thermal stratification, temperature, depth, light, sedimentation, etc. In general, biological activity in reservoirs will be conditioned by (a) the rate and amount of pollutants and sedimentary organic input to the reservoir system, (b) the water release schedule of the reservoir, and (c) depth within the water column, with the preponderance of biological activity occurring in the shallow water of the reservoir littoral zone (Lenihan et al. 1981).

Human and Other Processes

34. The final category of inundation-related processes include the various consequences of human activities, ranging from dam construction to site vandalism, and impacts associated with changes in land use following dam construction and reservoir impoundment. These changes, which tend to be focused in the reservoir backshore, include such things as development of recreation facilities, agriculture, livestock grazing, and so on.

35. Human impacts to cultural resources begin during the planning and construction phases of a reservoir. Prior to dam closure, there are direct impacts from borrow pit excavation, embankment construction, vegetation clear cutting, road building and realignment, and a host of other impacts associated with dam construction and site preparation. Following dam closure, direct human impacts continue along the reservoir shoreline and in the backshore and downstream zones.

36. Reservoir construction has an effect similar to highway construction in that it may open areas that were previously inaccessible to human visitation. Changes in land-use, especially the construction of reservoir recreation facilities, is a major source of adverse impacts. The typical freshwater reservoir serves as a magnet for a variety of developments: new roads, picnic and camping sites, hiking and riding trails, boat-loading ramps, arenas and waterside concessions, housing developments, etc. These developments are secondary to but often no less destructive of cultural resources than dam construction and freshwater inundation.

37. With the increased accessibility to cultural resources that reservoirs invariably provide, there is usually an accompanying increase in coincidental and purposeful vandalism of cultural values. Three kinds of vandalism typically accompany the construction of a new reservoir: (a) casual or unintentional vandalism resulting from the weekend relic collector (the inadvertent vandal seldom realizes that the removal of potsherds or projectile points from an archeological site or rocks from a building foundation are destructive of irreplaceable cultural resources); (b) indiscriminate vandalism, in which the vandal destroys or defaces everything from trees to cliff faces to cultural resources; and (c) purposeful vandalism, the activity of the professional pothunter and artifact collector.

38. Finally, many subtle changes in land use following the construction of a freshwater reservoir can have a host of negative impacts on cultural resources. Changes in livestock grazing patterns and intensity following freshwater impoundment may have serious impacts on cultural resources at the shoreline and in the reservoir backshore. Domestic livestock can overrun cultural sites at the water's edge, denude the landscape of protective vegetation, break surface artifacts, topple walls, deposit dung and foul cultural stratigraphy, and destroy the fragile stratigraphy of rock shelters.

PART IV: OVERVIEW OF INUNDATION IMPACTS

39. The NRIS used a variety of methodologies to address the issue of inundation impacts on cultural resources. Most of the data on impacts to large- and medium-scale cultural values were derived from field studies of inundated cultural sites and previously inundated sites exposed in reservoir drawdown zones. Personnel from NRIS traveled throughout the country visiting dozens of reservoirs to record inundation impacts firsthand. In addition, the National Park Service contracted with institutions to perform detailed inundation studies at 12 major reservoirs throughout the country. These contract studies used a standardized research design; detailed synopses of these studies are contained in the final report of the NRIS (Lenihan et al. 1981).

40. Most of the data on impacts to small-scale cultural values were derived from controlled field and laboratory experiments carried out by the National Park Service, the University of New Mexico, Texas A&M University, and Virginia Polytechnic Institute. Laboratory experiments were conducted to measure water chemistry and wetting/drying effects on a variety of common cultural materials, including wood, bone, stone, shell, and micro and macro plant remains. In addition, controlled field experiments were carried out at several reservoirs throughout the country to measure combined water chemical and biological impacts on cultural materials.

41. Some of the results of these studies are summarized in Table 2 and in the discussion that follows. The discussion is organized by reservoir impact zones, which correspond roughly to reservoir pool level states and management areas (Figure 3). The use of discrete impact zones acknowledges the fact that location within a reservoir impoundment is one of the most important variables influencing the nature and degree of impact to cultural resources. The NRIS used a five-zone model in reporting the results of its research in 1981. To simplify the following presentation, the NRIS model will be condensed to the following three critical impact zones:

Table 2

Contracted on Cooperative Field Studies Completed Under the NRIS (From Lenihan et al. 1981)

Location	Study	Source*
Chesbro Reservoir, California	Archeological Resources of Chesbro Reservoir	Winter 1977
	A Baseline Data Study of Three Archaeological Sites at Chesbro Reservoir	Stafford and Edwards 1980
	Inundation Effects on Thermoluminescence Response of Archaeological Lithics from Chesbro Reservoir	Rowlett and Bates 1979
	Results of Testing Inundation Impacts on Site CA-SCL-52 at Chesbro Reservoir	Stafford and Edwards 1980
Folsom Reservoir, California	The Effects of Inundation on the Pedersen Site, CA-ELD-201, Folsom Lake, California	Foster et al. 1977
	Archaeology in Solution: Testing Inundation's Effects at Folsom Reservoir, California	Foster and Bingham 1978
Lake Mendocino Reservoir, California	Supplementary Investigations into the Effects of Freshwater Immersion on Cultural Resources of the Lake Mendocino Reservoir Basin, Mendocino County, California	Stoddard and Fredrickson 1978
Grand Coulee National Recreation Area, Washington	Field Assessment	Carrell 1980a

(Continued)

* Bibliographical data for sources may be found in Lenihan et al. (1981).

(Sheet 1 of 3)

Table 2 (Continued)

Location	Study	Source*
Abiquiu Reservoir, New Mexico	The Mechanical and Chemical Effects of Inundation at Abiquiu Reservoir	Schaafsma 1978
Navajo Reservoir, New Mexico	Effects of Inundation on Archaeological Materials from the Navajo Reservoir	Rowlett and Bates 1979b
Lake Powell, Utah	Glen Canyon Revisited: The Effects of Reservoir Inundation on Submerged Cultural Resources	Rayl et al. 1978
	Preliminary Experiments in the Structural Preservation of Submerged Anasazi Masonry Units	Nordby 1980
Palmetto Bend Reservoir, Texas	Prehistoric and Historic Archeological Site Magnetometer Surveys in the Palmetto Bend Reservoir Area	Arnold and Prokopetz 1976
Libby Reservoir, Montana	Field Assessment	Carrell 1980b
Saylorville Reservoir, Iowa	Eyeing the Gathering Waters Whilst Building the Ark: Preparation of Archeological Site 13PK183 Saylorville Reservoir, Iowa, for Post-Inundation Study	Gradwohl and Osborne 1977
Table Rock Reservoir, Missouri	A Final Report on the Effects of Inundation on Cultural Resources: Table Rock Reservoir, Missouri	Garrison, May, Marquardt, and Sjoberg 1979

(Continued)

Table 2 (Concluded)

Location	Study	Source*
Bluestone Reservoir, West Virginia	An Inundation Study of Three Sites in the Bluestone Reservoir Summers County, West Virginia	Adovasio et al. 1980
	Inundation Effects on Thermoluminescence Response of Archeological Remains from Bluestone Reservoir, Summers County, West Virginia	Rowlett and Bates 1980
Blue Mountain Lake, Arkansas	Blue Mountain Lake: An Archeological Survey and an Experimental Study of Inundation Impacts	Padgett 1978
Tellico Reservoir, Tennessee	Experiments for Monitoring the Effects of Inundation on the Toqua Site (46MR6), Tellico Reservoir, Monroe County, Tennessee	Schroedl 1977
Ozark National Scenic Riverways, Missouri	National Reservoir Inundation Study Research at Round Spring and Alley Spring, Ozark National Scenic Riverways, Missouri	Carrell, May, and Garrison 1980

(Sheet 3 of 3)

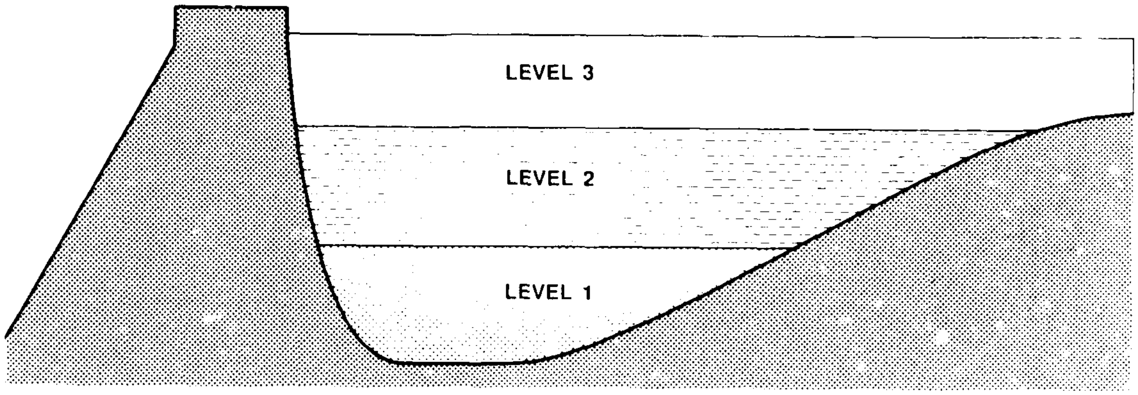

Figure 3. Reservoir impact zones (modified from Lenihan et al. 1981)

Zone	Location	Description
1	Conservation pool (includes sediment and water storage)	That portion of the reservoir below the average annual drawdown
2	Fluctuation or drawdown zone	The zone exposed to periodic, usually annual, shoreline fluctuation
3	Backshore zone	The upper, noninundated reaches of the reservoir watershed

42. Impacts within a reservoir impoundment change through time. During the initial flooding of a reservoir, mechanical impacts predominate, but after the permanent pool is established (Zone 1) and in the absence of underwater slumping and soil movement, the dominant processes impacting cultural resources are biochemical in nature. Within the fluctuation zone of a reservoir (Zone 2), mechanical impacts of wave and water motion will dominate during the life of the reservoir, although biochemical and human impacts are also very active in the littoral zone. In the backshore zone (Zone 3), in areas of the reservoir basin that are rarely if ever inundated, the dominant impacts will be human and land use related.

Zone 1: Conservation Pool

43. The conservation pool of most reservoirs is the scene of a variety of adverse impacts to cultural resources, and during the life of the reservoir, the kinds and intensities of impacts change.

44. During dam construction and site preparation in the conservation pool, human activities constitute the greatest threat to cultural resources. Adverse impacts may result from dam and embankment construction, borrow pit excavation, road construction and realignment, obstruction removal, vegetation clear cutting, and a host of other construction-related activities.

45. Following dam closure and during initial reservoir filling, mechanical hydrological impacts predominate. Wave impacts during initial filling will be conditioned by reservoir fill rate and the presence or absence of protective vegetation. Fill rate will be a function of stream inflow rates and basin slope (in general, the steeper the slope, the slower the fill rate, the greater the impact). The most effective vegetation cover is a dense understory of grasses or shrubs that buffers the impacts of initial immersion. In summarizing ideal conditions for cultural resource preservation during the initial filling episode, the NRIS concluded:

> From the standpoint of site preservation, an ideal combination of these variables would include a rapid, nonfluctuating pool rise; sites located on stable, gentle slopes that are rapidly inundated by rising impoundment waters; and a vegetation understory of dense grass to serve as a soil binder during initial inundation. To the extent that real-world conditions vary from this ideal, we may expect a variety of adverse impacts to occur to offshore sites during the period of initial reservoir filling (Lenihan et al. 1981).

46. If cultural resources survive the initial filling episode, they may be expected to be buried under a silt mantle where stable anaerobic conditions may actually enhance long-term preservation of cultural values. Until such burial occurs, there is the likelihood of biochemical decomposition of cultural materials, especially perishable organics. In general, decay rates for organic materials will be highest in the shallow littoral zones of reservoirs, where aerobic conditions contribute to organic decay. Decay rates decrease with depth and are lowest in the anaerobic bottom sediments in the deepwater zones of reservoirs.

> Under anaerobic conditions, the rate of degradation is slow due to the rapid accumulation of fermentation products which lower the pH

sufficiently to inhibit bacterial metabolism. Additionally, the lower temperatures of aquatic sediments tend to retard microbial metabolism and may, therefore, enhance preservation (Wetzel 1975).

47. Other factors influencing long-term preservation in the conservation pool include soil type, burial depth within the soil column, and chemical and biological characteristics of the impoundment. Some soils like clays, fine sands, and silts may act as mechanical barriers to microbial movement and activity. Although it is by no means certain how deep within the soil column microbial activity penetrates, some studies have suggested that very little activity occurs below a depth of approximately 1 m (Alexander 1961). This appears to be a function primarily of sediment compression and mechanical barriers to microorganisms. Consequently, biochemical decomposition should fall off dramatically after a silt mantle is deposited and the new reservoir ecosystem stabilizes.

48. Unfortunately, even the deep bottom sediments of the conservation pool are not immune to large-scale mechanical and other impacts. Subaqueous slope failures resulting from sediment saturation and liquefaction have been noted in many reservoirs (Sherman 1968). In the event of a severe drawdown, a variety of mechanical and other impacts may occur that degrade or destroy cultural resources that survived the impacts of dam construction and initial reservoir filling. During severe drought-related drawdowns in several California reservoirs in the mid-1970s, the empty, vegetation-free reservoir basins attracted large numbers of off-road vehicles that virtually destroyed a number of archeological sites that had survived for years under the silt and water column of the reservoir (Winter 1977) (Figure A2).

49. If cultural resources survive the mechanical effects of the initial filling and subsequent drawdown episodes, the primary impacts to cultural resources in the conservation pool will be biochemical in nature. The NRIS amassed a large body of data on freshwater inundation effects on common cultural materials. The following section summarizes some of the results of a series of differential preservation experiments conducted by the NRIS (for a more detailed discussion, see Lenihan et al. 1981, Vol 2).

Bone

50. The NRIS immersed samples of charred and uncharred bone from several species in 30 water-chemical solutions for a period of 1 year (Ware and Rayl 1981). In the majority of chemical environments, there was detectable

leaching of calcium, sodium, potassium, and magnesium following initial immersion, with the highest rates of degradation occurring, predictably, in the acidic water-chemical environments. Bone density, the amount of exposed surface area, and bone condition (charred versus uncharred) were significant variables determining bone degradation rates. These results replicated independent experiments by Von Endt and Ortner,* which concluded that bone size, surface area, and bone porosity are important variables in bone preservation. Predictably, bone was preserved best in alkaline environments with a pH of approximately 7.0. In acidic environments, bone minerals were dissolved, resulting in measurable deterioration of the bone matrix. Acidic conditions are typical of the anaerobic mud-water interface in most reservoirs.

Ceramics

51. The NRIS manufactured experimental ceramic chips in which such variables as clay mineralogy, firing temperature, firing atmosphere, and tempering materials were strictly controlled. Samples of the experimental ceramics were immersed for 1 year in laboratory-controlled water-chemical environments and in a reservoir substrate where samples were periodically monitored for quantitative and qualitative changes (Ware and Rayl 1981). Observed rates of deterioration, estimated by sample weight loss, changes in tensile strength, and visual degradation, were conditioned primarily by technological variables, especially firing temperature, with very little variation across water-chemical environments. The results suggest that most well-fired ceramics can be expected to survive long-term freshwater immersion.

Stone

52. Flakes of chert and obsidian were immersed in 30 laboratory solutions and in test containers in the field. After 12 months of immersion, no measurable changes were detected.

Wood

53. Wood is rarely preserved in archeological contexts because of its susceptibility to fungal and bacterial degradation. Experiments conducted by the NRIS suggest that hard woods (oak) are more susceptible to degradation than soft woods (pine), perhaps because the high lignin content of most soft

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* David W. Von Endt and D. J. Ortner. 1977. "Chemical Alterations in Buried Bone: Their Effect on Paleoecology and Related Archaeological Problems." Unpublished manuscript on file at US National Park Service, Southwest Regio ffice, Santa Fe, NM.

woods protects the cellulose from predator attack (Ware and Rayl 1981). All wood specimens immersed in laboratory ionic solutions exhibited measurable weight loss following an 8-month immersion period, with the most significant weight losses occurring in salt, magnesium chloride, calcium chloride, and magnesium sulphate solutions. The NRIS concluded that wood degradation rates are influenced by wood species, sample condition (charred versus uncharred), and biochemical environment.

Shell

54. Calcium carbonate, the principal chemical constituent of shell, is not very soluble in pure water. However, in the presence of high carbon dioxide concentrations, calcium carbonate reacts to produce carbonic acid and soluble bicarbonate (Lenihan et al. 1981). This same process should occur within reservoirs, the rate of reaction depending on such variables as depth of burial, pH, temperature, and water ionic concentrations. In controlled laboratory immersion experiments, oyster and clam shell degradation rates were greatest in acid and sodium chloride solutions (Ware and Rayl 1981). Measurable calcium leaching was also observed in field immersion experiments, suggesting that prolonged inundation may adversely affect shell preservation.

Seeds

55. The NRIS immersed seven seed taxa (common kidney, pinto, and navy beans; popcorn, blue corn; wheat; and rye) in 30 laboratory-controlled ionic solutions for a period of 1 year and estimated deterioration rates by periodically measuring such variables as seed dimension, weight loss, and qualitative changes in seed coats, endosperm, and cotyledons (Ware and Rayl 1981). Although deterioration of all seed taxa across all water-chemical environments was measurable, no significant differences were observed between water-chemical environments. Another somewhat unexpected observation in the laboratory experiment was that charred seeds deteriorated more rapidly than uncharred seeds. Apparently, the charring process damaged and weakened the seed coats, and immersion exacerbated this damage. Of the seed taxa examined, the three bean varieties exhibited the most significant degradation, followed by corn, wheat, and rye.

Pollen

56. Thirteen pollen taxa were immersed in the laboratory and in the field experiment (Holloway 1981). Half of each taxon sample was acetylated (the cytoplasm was removed) to simulate fossil pollen. In the laboratory

experiment, the acetylated pollen exhibited less deterioration than the fresh pollen, and the variable "time of immersion" was a significant treatment effect, with most degradation occurring following the first few days of immersion. Pollen exine (outer shell) deterioration was most significant in sodium silicate and chloride solutions.

57. Four preservation effects were studied in the field experiment: (a) location within the reservoir, (b) duration of inundation, (c) position in the water column and sediment substrate, and (d) acetylated (fossil) versus unacetylated (modern) pollen. Of the four treatment effects, duration of immersion was the most significant, with location within the reservoir the second most important effect (the highest rates of deterioration were associated with a limestone substrate with minimum sediment cover). Position of pollen in the water column and fossil versus modern pollen were judged to have little effect on deterioration rates in the field experiment. In both field and laboratory experiments, thin-walled exines were more susceptible to degradation, as would be expected.

58. In summarizing the results of preservation experiments on common organic materials, the NRIS concluded:

> The survival of pollen, seeds, and organic matter in a reservoir will largely depend on the initial depositional episode, subsequent environmental events, and the physical and chemical properties of the inundated soil matrix. Deeply buried (e.g., greater than 40 cm) materials will probably show few adverse effects resulting from inundation, since microbiological activity is considerably reduced and the soils tend to exhibit low redox potential. Materials deposited on or near the surface (less than 10 cm) are more susceptible to oxidation processes and microbiological activities. Consequently, preservation of these materials will depend on the local reservoir conditions (Lenihan et al. 1981).

59. The results of differential preservation experiments conducted by the NRIS suggest that several categories of common cultural material may be expected to survive long-term freshwater inundation. However, if cultural materials are preserved in reservoir conservation pools throughout the country, it is perhaps legitimate to ask why and for what purpose. Man-made lakes are essentially closed systems in which sediment input greatly exceeds sediment output. As a result, water storage capacity gradually declines through time until the reservoir basin fills with sediment to the level of the dam spillways. Cultural resources buried under tens of metres of unconsolidated sediments are clearly not accessible for research, and very little is

known about the long-term impacts of deep sediment burial. In addressing this important issue, the NRIS concluded:

> Research . . . has shown that many archaeological resources may be preserved from significant damage resulting from inundation, but this could prove meaningless if accessibility to the resource is severely compromised (Lenihan et al. 1981).

Zone 2: Fluctuation Zone

60. Within the shoreline fluctuation zone of most man-made reservoirs, virtually all categories of cultural resource impacts are magnified, with mechanical hydrological impacts constituting the greatest threat to cultural resources. Wave action poses the most serious threat in the reservoir fluctuation zone (Figure A3). Important variables include wave approach, wave intensity, and shoreline geomorphology. The interaction of these variables will determine the formation and configuration of the shoreline and the high-energy beach zone.

61. The nature and extent of beach zone mechanical impacts will be influenced by four variable conditions: (a) reservoir size, depth, and orientation, local climatic regime, and the operating characteristics of the reservoir; (b) cultural site location relative to reservoir fetch and prevailing wind patterns; (c) site geological and environmental context (especially the slope and erosion resistance of basin geomorphology); and (d) the character and erosion resistance of cultural deposits.

62. The intensity of wind-wave impacts in the fluctuation zone will be a function of the strength of prevailing winds, the frequency and intensity of storm waves, and the size of the reservoir fetch. These predictions are complicated, however, by frequent pool-level fluctuations. With a stable pool level, beach zone erosion is a self-limiting process resulting from offshore shoal formation, but the development of an equilibrium beach profile is frustrated by fluctuating pool levels and an expanding and contracting beach zone that erodes offshore shoals, creating unstable shorelines.

63. Even under ideal conditions, development of an equilibrium beach profile is dependent on such factors as shoreline slope, soil type and gradation, and the frequency and intensity of storm waves. In general, shoreline formation is much more predictable in sandy, poorly consolidated soils and much less predictable in well-consolidated, clayey, or heavily vegetated

soils. Unfortunately, most man-made reservoirs experience periodic pool-level fluctuations as a result of the alternating storage and release of water. Fluctuations are especially common in reservoirs used for agricultural irrigation storage or hydroelectric power generation.

64. Fluctuating pool levels enlarge the zone of destructive wave action by increasing the effective beach zone of a reservoir:

> As the reservoir pool level draws down, breaking waves strike the saturated and unconsolidated sediments of the reservoir basin which have already been deprived of a protective vegetative cover. These fragile sediments are susceptible not only to wave erosion but also to subsequent wind and water runoff erosion within the exposed drawdown zone (Lenihan et al. 1981).

65. Another important factor that determines the nature and extent of mechanical impacts in the fluctuation zone is the slope, orientation, exposure, and constituency of the shoreline geology (Figure A1). The slope of the reservoir basin is particularly important. Steep to near-vertical slopes of poorly consolidated sediments encourage the development of erosional cutbanks where wave action gradually undercuts a vertical face, resulting in the slumping of unsupported blocks of soil. On Oahe Reservoir and other impoundments along the Missouri mainstem in South Dakota, shoreline cutbank erosion of poorly consolidated loess deposits is so severe that dozens of important archeological sites are currently threatened (Figure A1). On flatter reservoir slopes, sheet erosion is more common, and on nearly flat terrace slopes, erosion is minimal.

66. The fourth and final variable in the shoreline mechanical impact equation is the nature and erosion resistance of the cultural resource itself. By and large, the relationships among the objects comprising a site are more susceptible to high-energy mechanical impacts than the objects themselves. Consequently, archeological context is often the first thing to be compromised when a site is subjected to shoreline erosion.

67. Whereas very little is known about deepwater impacts to cultural resources, a great deal of comparative data is available on shoreline impacts, in part because sites that are periodically exposed are more accessible to scrutiny. Archeological surveys of drawdown zones indicate that waves and nearshore currents can dislodge and displace large artifacts. Extensive impacts to architectural features and archeological midden deposits have also been reported. At Wister Reservoir in Oklahoma, Galm (1978) reported that

several large prehistoric midden sites were virtually leveled by shoreline wave erosion. Similar effects have been observed at reservoirs throughout North America (Lenihan et al. 1981).

68. In addition to the high-energy impacts of water motion in the reservoir fluctuation zone, frequent wetting and drying of cultural deposits on the shoreline poses a significant threat to a wide variety of cultural materials. To quantify the impact of frequent wetting and drying in reservoir fluctuation zones, the NRIS performed a series of laboratory experiments in which a variety of common cultural materials were subjected to multiple wet/dry cycles. Samples of animal bone subjected to 30 wet/dry cycles exhibited evidence of deterioration in the form of cracking, cortical lifting, and shrinkage (on many elements up to 1 percent). Samples of animal teeth, which are normally very resistant to weathering and mechanical degradation, were seriously reduced by extensive cracking and spalling. Samples of plant pollen subjected to 50 wet/dry cycles exhibited serious degradation in over 70 percent of the treated samples. The NRIS concluded that wetting and drying exposure contributes to the deterioration of common organic materials and that much of the deterioration occurs after only a few exposures.

69. Although mechanical impacts predominate in the reservoir fluctuation zone, the potential for biochemical and human impacts on the shorelines of reservoirs is greater than in any other reservoir zone. Biochemical activity is accelerated in the shallow waters of the reservoir littoral zone because of higher light, dissolved oxygen levels and ambient temperatures. These conditions will support more organisms that may degrade perishable cultural materials. Similarly, the potential for human and faunal impacts is greater in the shoreline fluctuation zone than in any other reservoir zone. Human recreation and all its attendant impacts are concentrated at the reservoir shoreline: boat ramps, swimming beaches, campgrounds, recreational vehicles, power boats, and their destructive wakes are all potential sources of adverse impact to fragile cultural resources.

70. As human use and visitation of the lake shore increases, vandalism invariably increases. Since native vegetation is often deflated along the periodically inundated shoreline, cultural resources are often highly visible and, therefore, more susceptible to human impact.

Zone 3: Backshore Zone

71. The reservoir backshore is the area above the level of the maximum flood pool, extending upstream and upslope to include much of the reservoir watershed. There are no direct mechanical or biochemical impacts in the reservoir backshore, but other impacts can be anticipated that are directly related to reservoir construction and use. Reservoir construction may result in increased access to an entire watershed, making previously inaccessible areas readily accessible to anyone with a boat and an inclination to explore. A marked increase in cultural resource vandalism goes hand-in-hand with the construction of a new reservoir, and destructive changes in watershed land use may further degrade cultural resources.

72. The NRIS documented numerous instances of backshore vandalism that were clearly related to the problem of increased accessibility (Lenihan et al. 1981).

> An historic mining camp in Lake Shasta Reservoir, California, once a six-mile walk from the nearest road, was only a ten minute walk after the reservoir flooded. In an excellent state of preservation prior to pool filling, the site was completely destroyed within two years by individuals who removed the bricks and wood from the historic structures. . . . Numerous sites in Glen Canyon have been so severely impacted by picnickers that they can be considered a total loss. . . . Prehistoric wall alignments were dismantled and used to make campfire hearths by boaters and campers in Lake Roosevelt, Arizona (see Figure A5).

73. In addition to outright vandalism, changes in land use following reservoir impoundment can have adverse impacts on cultural resources. The reservoir backshore attracts housing developments, picnic areas, campgrounds, hiking and riding trails, new roads, boat ramps and parking lots, lakeside concessions, and a host of other developments that extend the impacts of reservoir construction well beyond the margins of the impoundment.

74. The impacts of domestic livestock pose additional threats to fragile cultural resources. Increases in livestock grazing following fresh-water impoundment may have a serious impact on backshore resources: cattle trampling breaks up artifacts on the ground surface; cattle also topple standing walls, wallow in the soft soil of trash middens, and destroy the fragile stratigraphy of rock shelters.

PART V: SUMMARY AND CONCLUSIONS

75. An effective cultural resource management plan for reservoirs and waterways begins with the recognition and understanding that there are discrete zones of differential impact within the typical reservoir environment. For management purposes, the three impact zones defined previously are most critical: (a) the conservation pool, (b) the fluctuation zone, and (c) the backshore zone. Cultural resource management strategies must reflect an understanding of the primary impacts that occur within each of these zones.

76. The conservation pool consists of that portion of the reservoir below the level of the average annual drawdown. Cultural resources within this permanently inundated zone are affected by the initial filling episode and remain inundated during the life of the reservoir, except in instances of severe drawdown. Within the conservation pool, primary mechanical impacts occur during dam construction, site preparation, and initial reservoir filling. If cultural resources survive these initial impacts, they may be preserved indefinitely under a stable silt and water column. Long-term mechanical impacts associated with deepwater inundation are poorly understood, and biochemical impacts in the conservation pool will tend to decline through time as the reservoir ecosystem stabilizes and as a silt mantle accumulates. Although certain perishable materials that survive initial inundation may be preserved indefinitely in the cold, dark bottom sediments of a freshwater reservoir, these data will not be available for study and appreciation during the life of the reservoir and beyond.

77. The shoreline fluctuation zone includes that portion of the reservoir that is periodically exposed to shoreline and nearshore wave action and wave-induced currents. The erosional impacts of water motion in the shoreline zone are often accompanied by wetting and drying, freezing and thawing, and invader floral and faunal effects. Biochemical processes are accelerated in the shallow water of the pool fluctuation zone because of increased light and dissolved oxygen, higher water temperatures, etc. Other impacts such as human vandalism and faunal intrusion are also greater at the reservoir shoreline than in any other impact zone. In situ cultural resource preservation in the shoreline zone is, at best, only a temporary alternative to more active mitigation measures (Figure A6). Intensive salvage excavation will usually be less expensive and more effective than the construction of hydraulic

engineering structures that must be monitored and maintained during the use life of the reservoir (Ware 1981). To paraphrase the recommendations of the NRIS, the cost of maintaining a protective structure in the high-energy beach zone must be added to the cost of initial installation, making site stabilization in the shoreline fluctuation zone an open-ended investment (Lenihan et al. 1981).

78. The backshore zone includes those areas beyond the reach of the maximum flood pool. The primary impacts in the backshore relate to human use of the reservoir and its watershed. A recreational reservoir may open previously inaccessible areas to human use and misuse, which may compromise cultural resources located miles beyond the reservoir shoreline. There is often little or no concern among reservoir managers and managing agencies about impacts to cultural resources in the backshore; yet this is one area where managers can do the most to protect sites without resorting to expensive mitigation measures.

79. In conclusion, field and laboratory studies of inundation impacts to cultural resources have determined that detailed documentation and excavation of cultural resources within the conservation pool and shoreline fluctuation zone is usually the most effective and nearly always the least expensive method of mitigating adverse impacts. Although in situ protection measures in these zones have been and should continue to be investigated, the long-term cost of protection and maintenance within the conservation and shoreline fluctuation zones is usually prohibitive.

80. The effectiveness of long-term protection measures within the conservation pool of a reservoir is also largely unknown. Although burial of cultural resources within deepwater sediments has been proclaimed an effective preservation option by some, the long-term mechanical and biochemical effects of deepwater burial are poorly understood. In addition, the question of future accessibility has never been honestly addressed by the "reservoir data bank" advocates. The notion of an archeological and historical data bank is untenable unless one can demonstrate the feasibility and practicality of future data withdrawals.

81. In situ protection as a mitigation alternative is perhaps only viable in the backshore of reservoirs where there are no direct inundation effects. Active protection of cultural resources in the backshore zone is perhaps the most important long-term cultural resource management

responsibility of reservoir managers. Unfortunately, backshore and downstream impacts are rarely perceived, let alone systematically addressed.

82. Many questions relating to cultural resource management in reservoirs have not been adequately addressed. Specifically, more and better controlled field studies of cultural resource impacts in reservoir drawdown zones are necessary to expand and clarify the results of a number of unsophisticated and highly impressionistic studies accomplished during the last two decades. Additional laboratory and field studies are also necessary to assess the effectiveness and practicality of various in situ site protection methods. Hydraulic technology is constantly evolving, and it is possible that new soil and bank stabilization technologies can be applied in the future to protect resources that are rapidly disappearing along the banks and shorelines of North American reservoirs and waterways.

83. In addition, there is still a great deal of basic research to be conducted on biochemical degradation processes in freshwater environments; this research may lead to more effective management of submerged or periodically inundated cultural resources.

84. Perhaps the most important area for future research is on the problems associated with cultural resource management in the reservoir backshore. Monitoring backshore resources along thousands of miles of inland shorelines is only part of the solution. More active protection and maintenance programs will be necessary on many reservoirs to ensure the survival of important cultural values. Creative use of vegetation and chemical soil stabilization technologies, site camouflage techniques, nondestructive land-use practices, public education, and more effective law enforcement will no doubt be part of an evolving management strategy for the backshore.

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APPENDIX A: PHOTOGRAPHIC DOCUMENTATION OF INUNDATION IMPACTS TO CULTURAL RESOURCE SITES (PHOTOGRAPHS PROVIDED COURTESY OF THE NATIONAL PARK SERVICE, SUBMERGED CULTURAL RESOURCES UNIT)

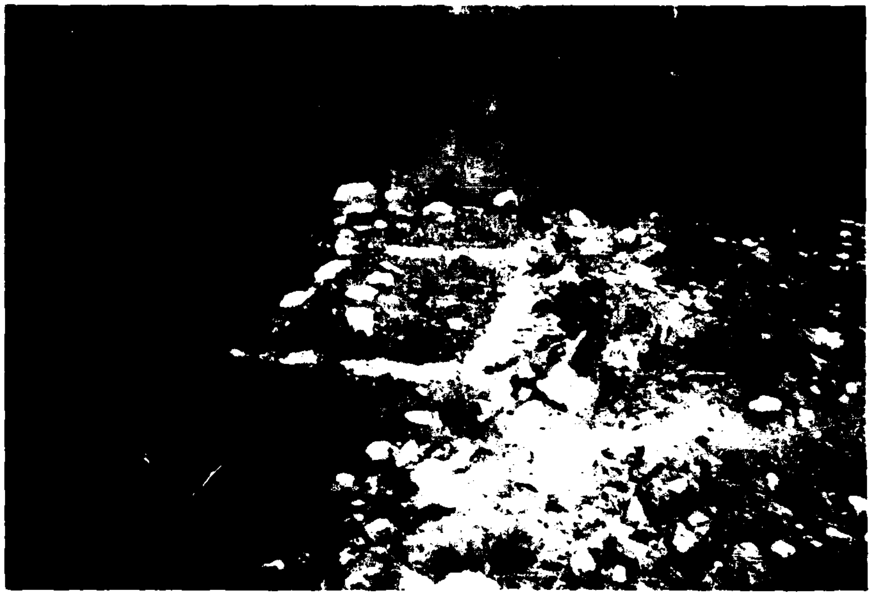

Figure A1. The geology and gradient of the reservoir shoreline have an important influence on shoreline impacts. The 12th-century Pueblo roomblock in top photograph suffered very little impact from the rising waters of Cochiti Reservoir in northern New Mexico. The site was protected, in part, by the gradual slope of the reservoir shore. The severe cutbank erosion illustrated in bottom photograph is typical of poorly consolidated glacial loess deposits. This photograph was taken along the shore of Fort Randall Reservoir in South Dakota, where a number of very important archeological sites are threatened by rapidly advancing shoreline erosion

Figure A2. Reservoir drawdowns provide a unique opportunity to evaluate the impact of freshwater inundation on cultural resources. During severe drought-related drawdowns in Folsom and other California reservoirs in 1976-77, several inundation impact studies were undertaken. In the top photograph, "pedestalled" oak tree stumps document the loss of nearly a metre of sediment from the permanent pool zone of Folsom Reservoir. At the prehistoric Pederson Site in Folsom Reservoir, prehistoric house floors proved to be more erosion resistant than the surrounding soil matrix (bottom photograph)

Figure A3. Many important cultural resources in the fluctuating shoreline zone of Lake Powell, Utah, were obliterated by wave impacts during the initial filling episode in the 1960s. Gourd House, a prehistoric cliff dwelling in Lake Canyon, is shown in top photograph as it appeared in the late 1950s. Virtually all that remained of the site in the late 1970s (bottom photograph) were a few scattered sandstone blocks, remnants of 3-m-high standing walls, and a row of "loom anchors" on the floor of the site alcove (visible immediately to the left of the tape measure)

Figure A4. Architecture is especially susceptible to shoreline mechanical impacts. This prehistoric Salado Pueblo, located within the permanent pool zone of Roosevelt Reservoir in Arizona, was reduced to a mound of cobble rubble by the advancing and retreating waters of the reservoir (top photograph). The bottom photograph shows the site in relation to Roosevelt Dam

Figure A5. Many impacts to cultural resources are secondary to the direct impacts of freshwater inundation. The top photograph shows the remains of a historic mining camp that was made accessible to vandals by the rising waters of Shasta Reservoir in northern California. In less the 2 years, the camp was virtually leveled by artifact hunters and collectors. The bottom photograph shows campers and boaters on a prehistoric site on the shore of Roosevelt Lake, Arizona

Figure A6. Initial attempts to stabilize a Paleoindian site on the shore of Oahe Reservoir in South Dakota were unsuccessful. The top photograph shows the site after it was stabilized with polyethylene sheeting; the bottom photograph was taken a day later after a single storm hit the beach